Development of Improved Fatigue Crack Growth Test Methods and Analytic Models Applicable to Aircraft Propellers

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Overview

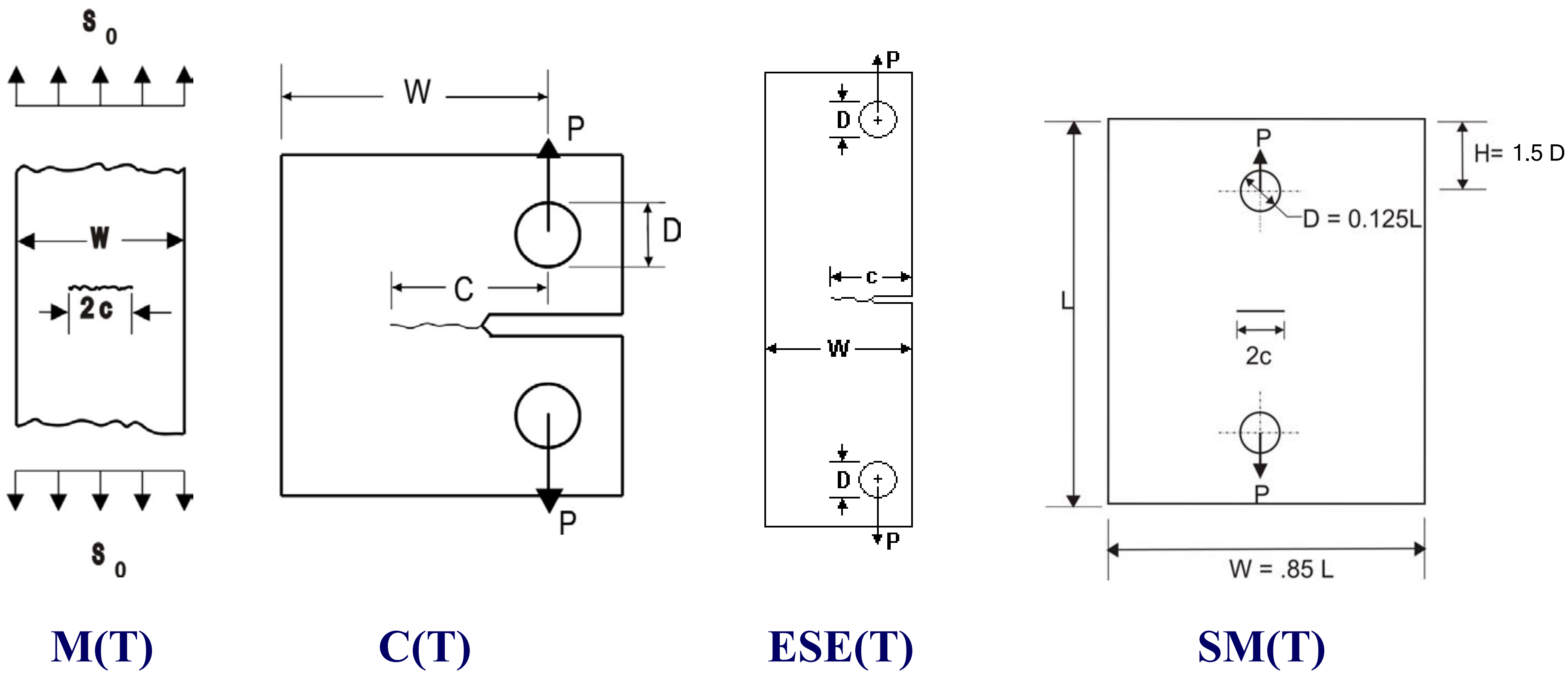
Principal tasks:

- **Develop and evaluate fatigue crack threshold testing methods**
- **Evaluate validity and accuracy of commonly used analytic models for DTA of rotorcraft.**

Specimen Configurations

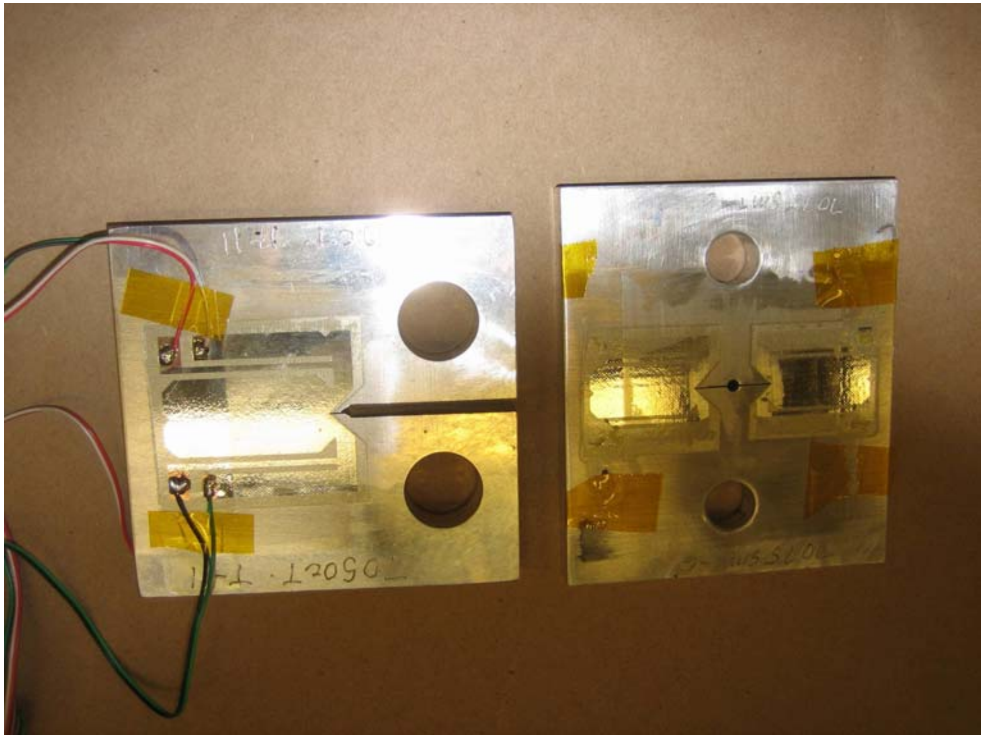
Testing Progress for last 6 months at JSC:

- **Threshold testing completed on Ti-6-4 MA specimens to compare threshold values between C(T), ESE(T), M(T) & SM(T) designs.**



SM(T) Specimen Benefits

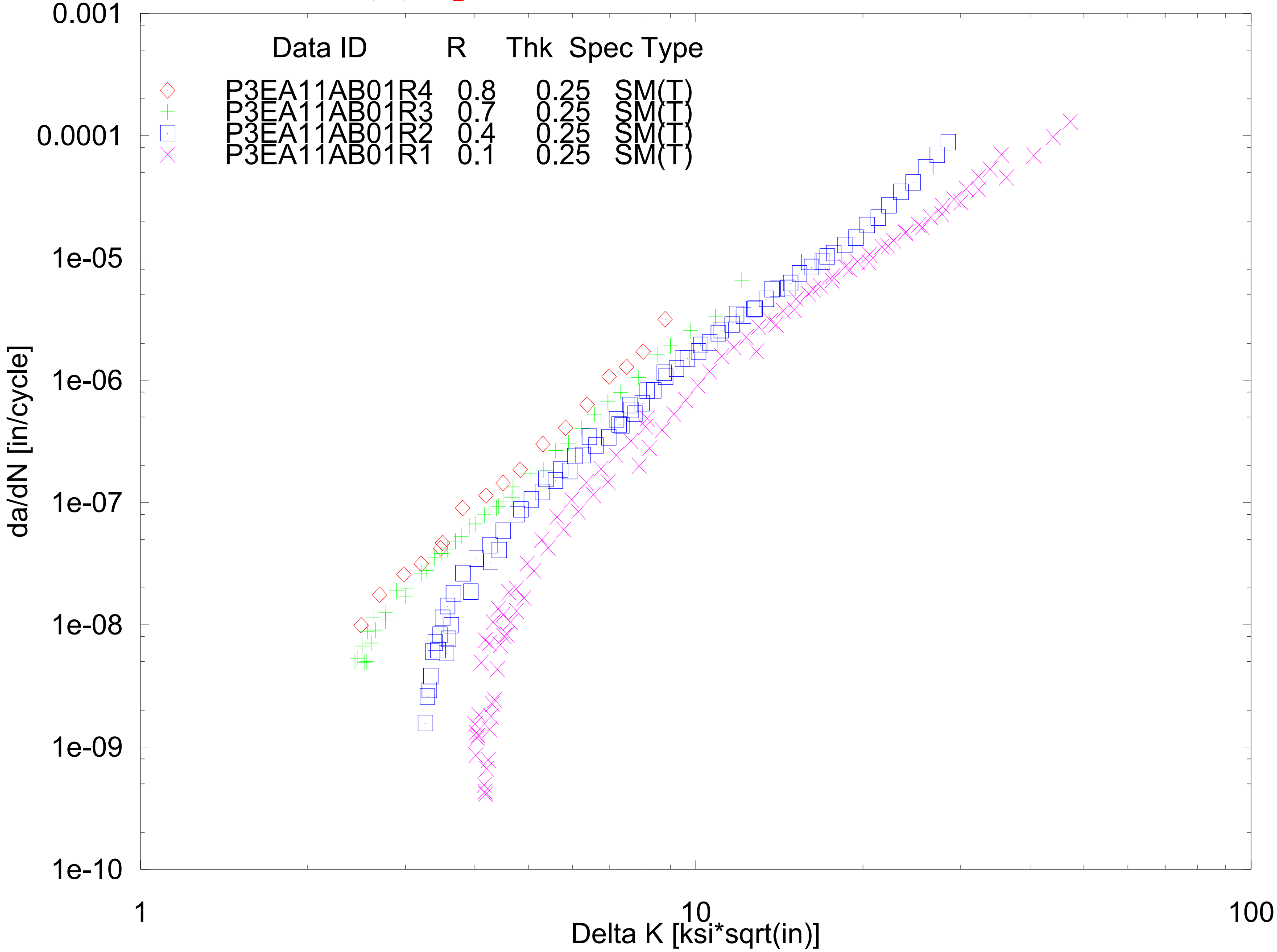
- **Crack has less tendency to turn compared to the C(T) specimen**
- **Specimen has high stiffness - allowing high cyclic frequency**
- **Requires much less material than for an M(T) specimen.**



Comparison of W=3” C(T) specimen with W=3.4” SM(T) specimen.

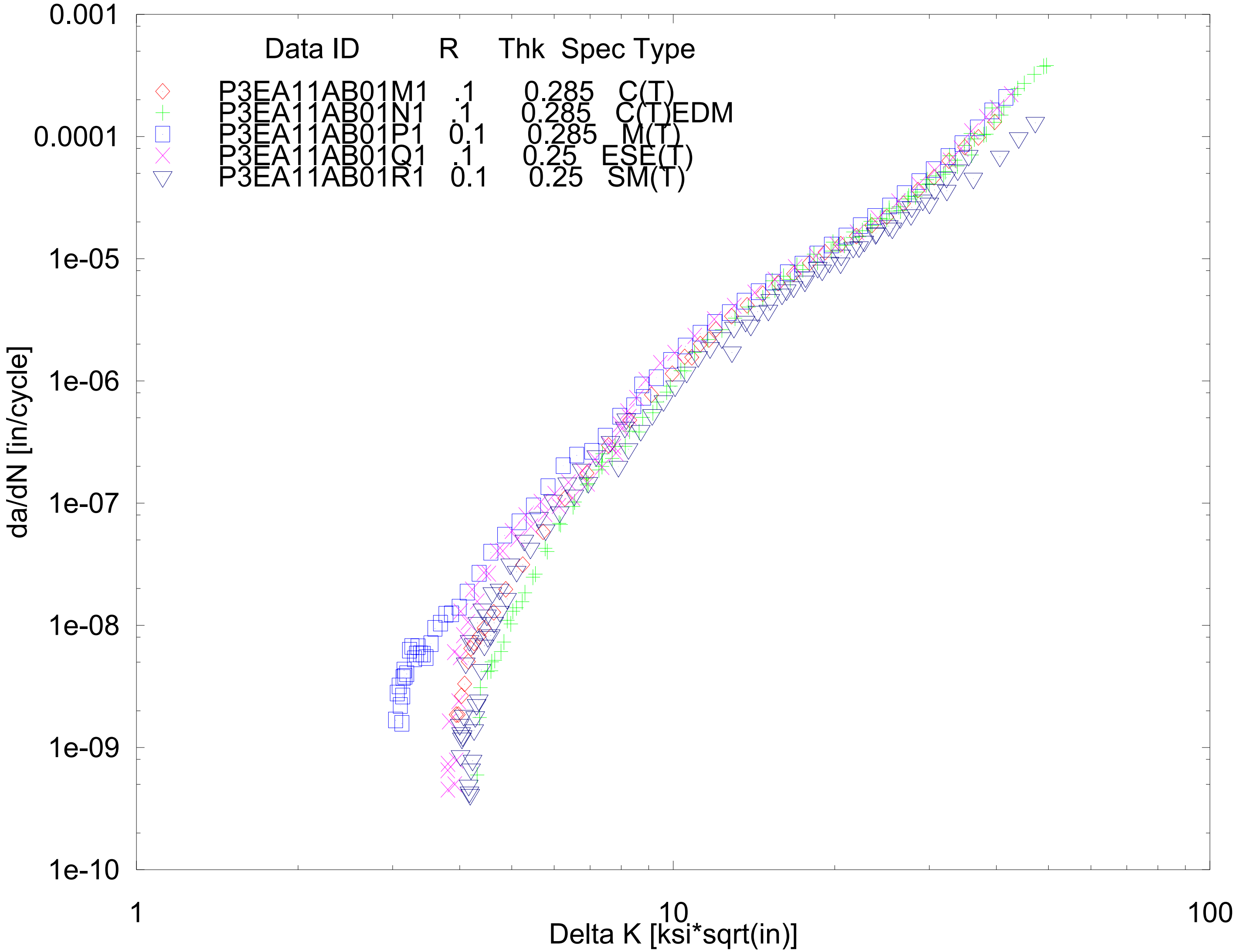
Ti-6Al-4V Mill Annealed Titanium

SM(T) Specimen Data for Ti-6-4 Plate



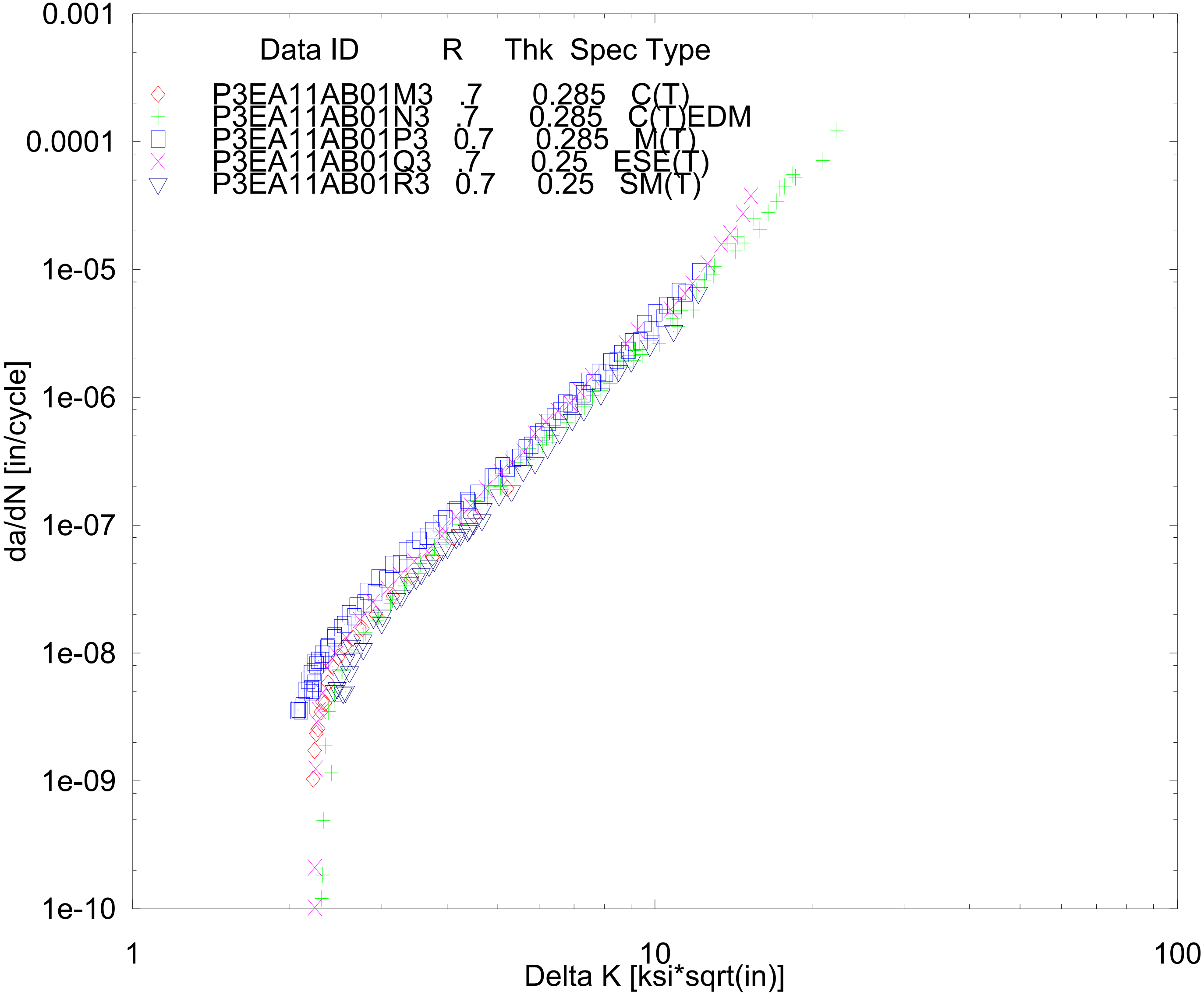
Ti-6Al-4V Mill Annealed Titanium

Comparison of R=0.1 Ti-6-4 Data for Different Specimen Types



Ti-6Al-4V Mill Annealed Titanium

Comparison of R=0.7 Ti-6-4 Data for Different Specimen Types

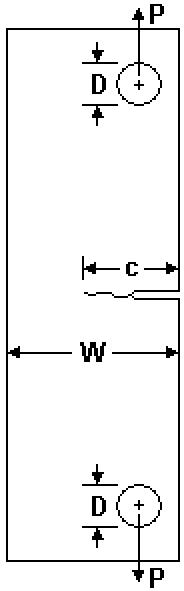


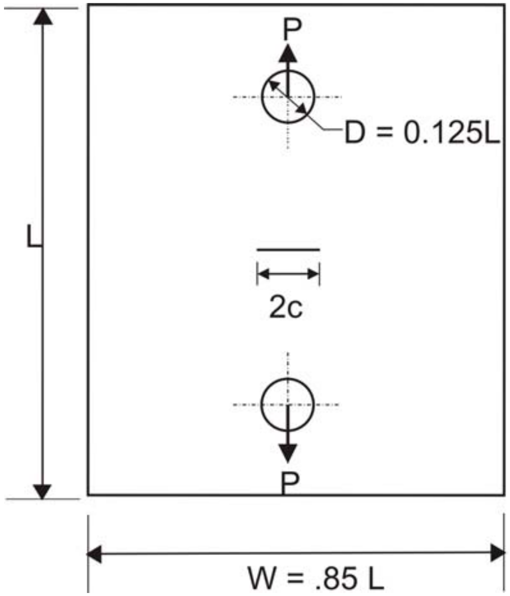
2025-T6 Propeller Blade

Testing Progress for Last 6 Months (Continued):

2025-T6 Propeller – Testing completed on 8 ESE(T) specimens machined from shank. Testing of SM(T) specimens to soon begin.

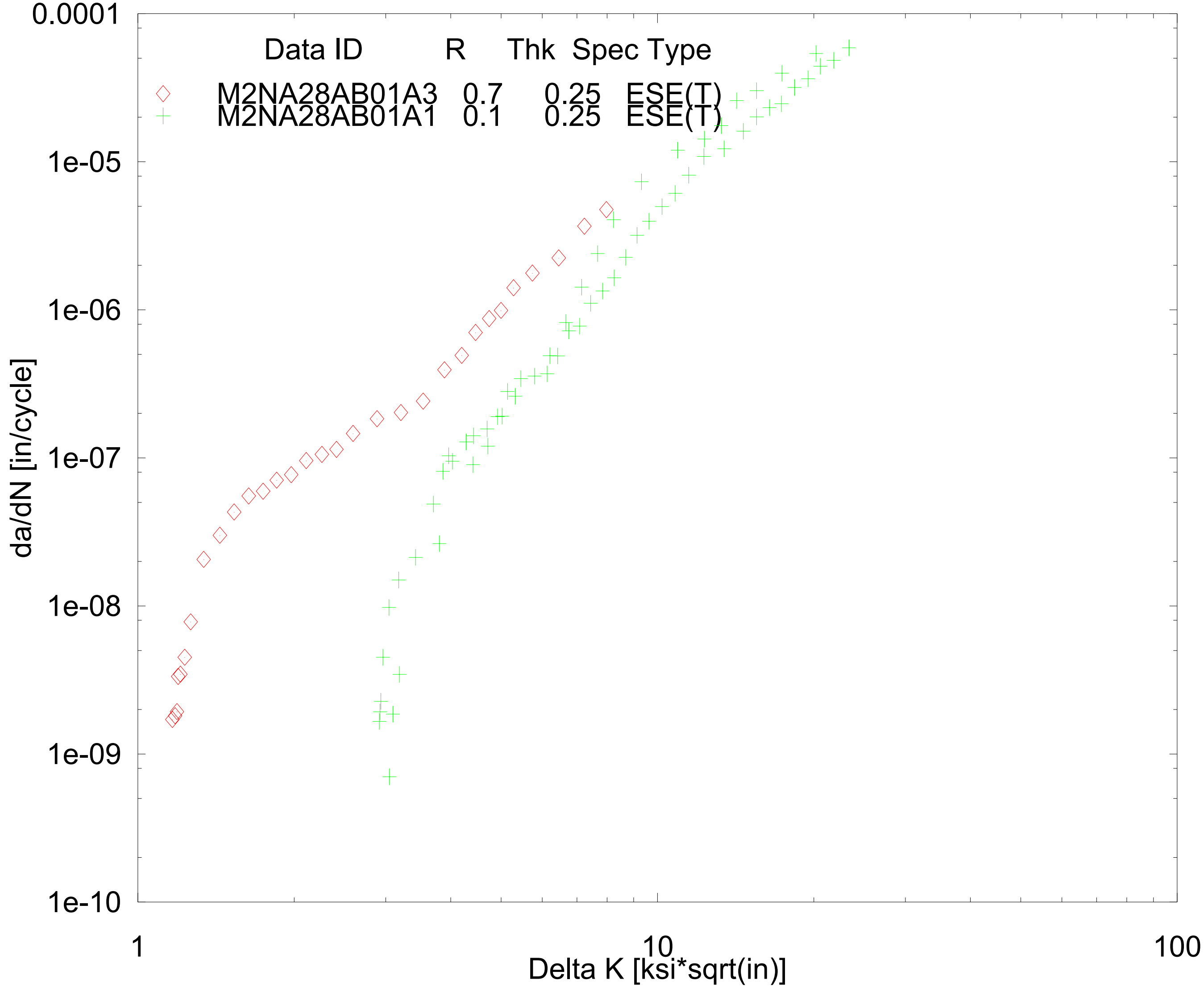
Specimen Types:





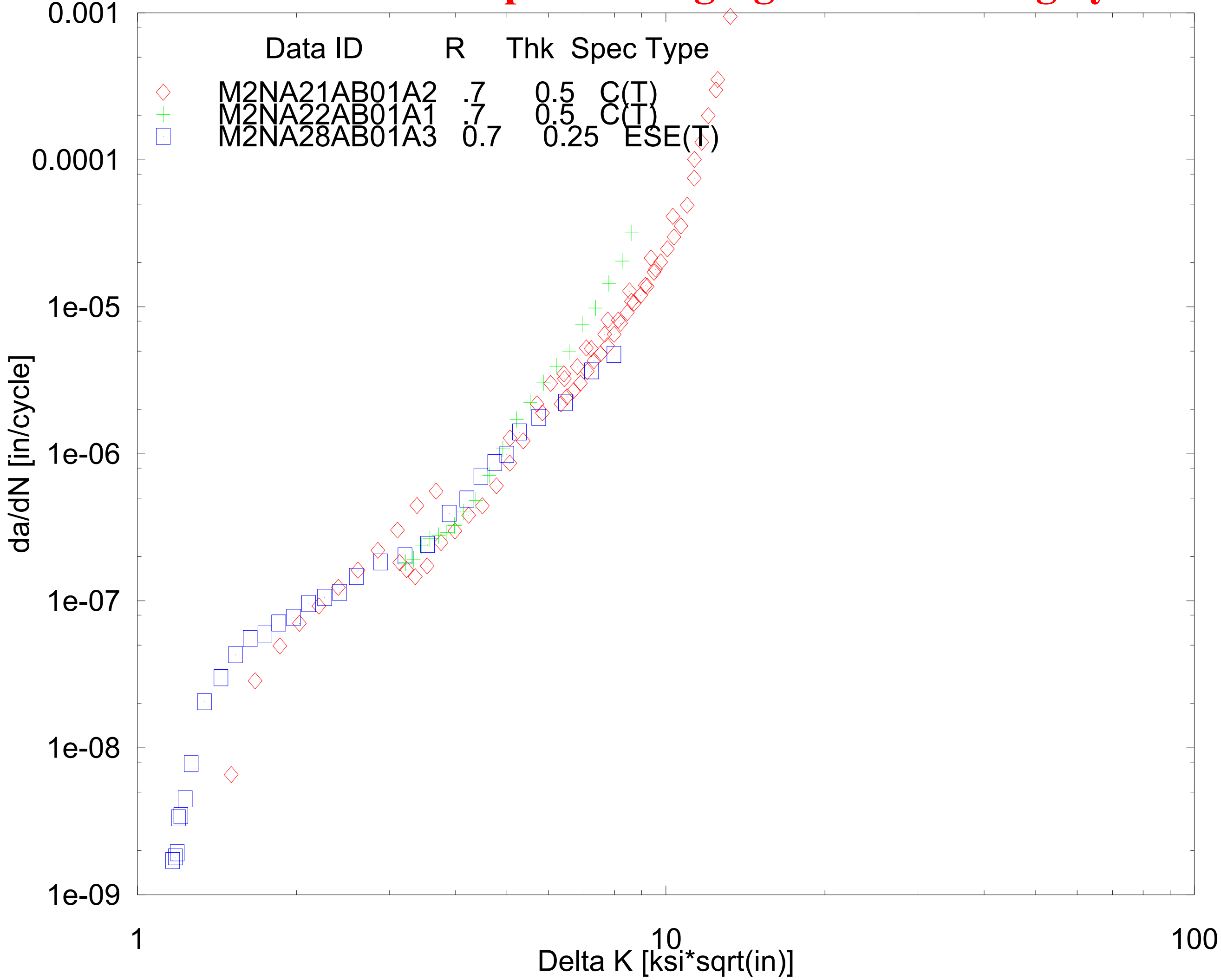
2025-T6 Aluminum

R=0.1 & 0.7 Test Results for 2025-T6 Propeller Forging, ESE(T) Specimens



2025-T6 Aluminum

R=0.7 Data for 2025-T6 Propeller Forging – JSC & Langley Results



2014-T6 Propeller Hub

Testing Progress for last 6 months (Continued):

- **2014-T6 Hub Forging (from Alcoa) – Completed testing 6 of 8 ESE(T) specimens. Testing of 6 SM(T) specimens to follow.**

Additional Propeller Material Testing

Testing Progress for last 6 months (Continued):

- **D6AC steel**

  (a) 14 machined specimens were heat treated to required RC 35 (180 UTS) condition; Surface regrinding is next step.

  Note: 10 specimens were tested in the as forged RC19 condition.

  (b) Blanks for 38 surface crack specimens were heat treated to RC 35. Final machining of these to the dog-bone shape will shortly begin.

- **4340 steel** – 34 previously machined specimens to be soon heat treated.

- **7075-T7351** – 40 dog-bone shaped specimen were machined and sent to Hamilton-Sundstrand for shot-peening and laser surface notching.

NASA Laboratory Upgrades

Recent NASA Funded Equipment Purchases To Improve Testing Capabilities:

- **Ordered 2 additional 10 Kip MTS fatigue machines with FTA automated testing systems (to give a total of 8 test systems) - $100K**

- **Purchased 2 direct potential drop crack measurement systems needed for testing surface crack specimens - $22K**

- **Refurbished 4 measuring microscopes to give digital readout - $12K**

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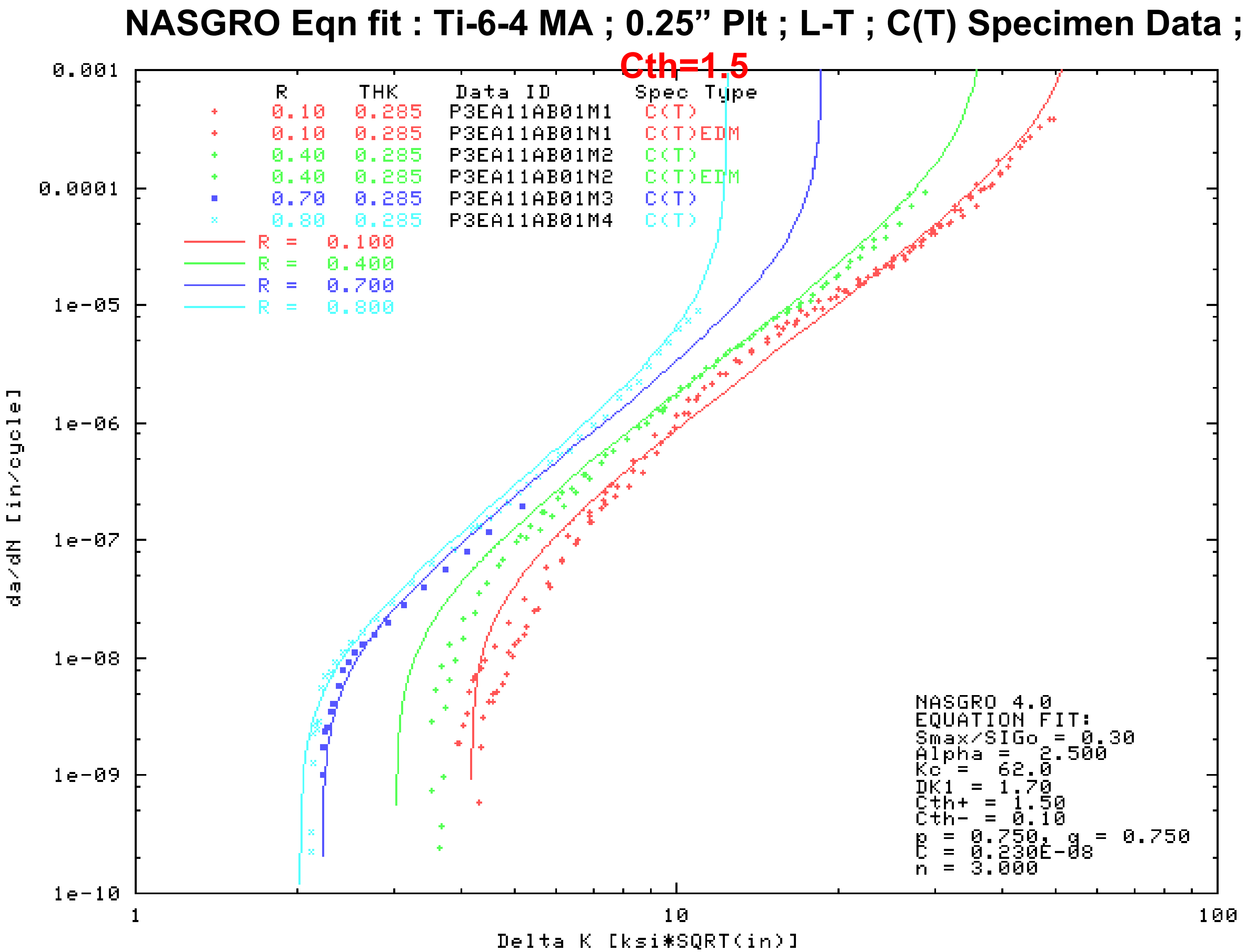
Ti-6Al-4V Mill Annealed Titanium



Newman Closure and Walker Equations

Newman Eqn:

$$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^{n}$$

where

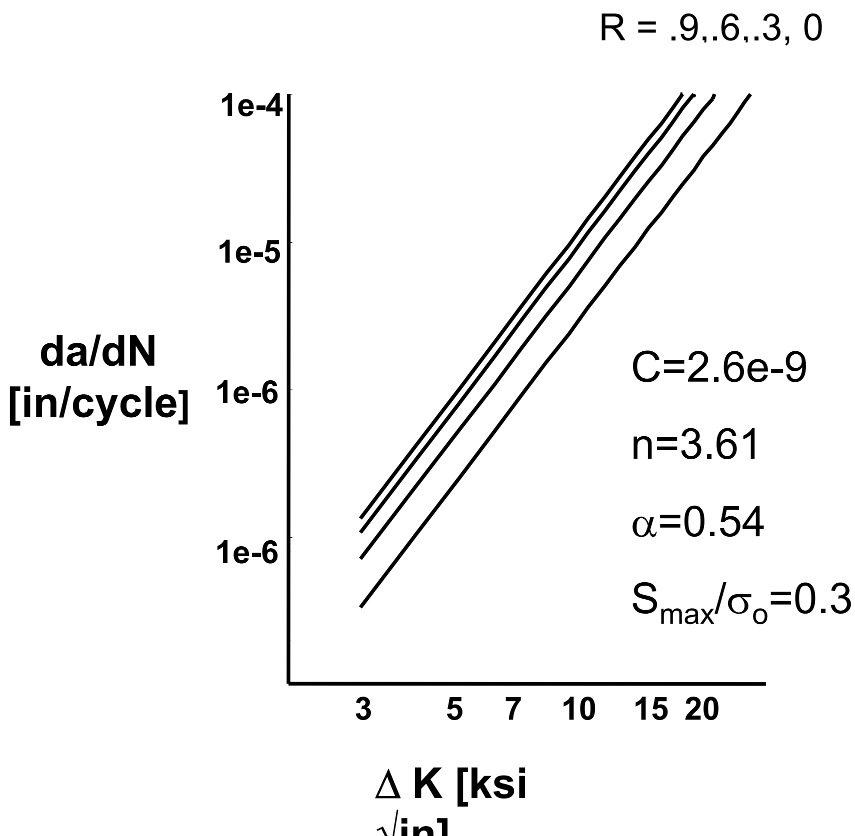
$$f = \frac{K_{op}}{K_{\max}} = \begin{cases} \max\left(R,\ A_0 + A_1 R + A_2 R^2 + A_3 R^3\right) & R \geq 0 \\ A_0 + A_1 R & -2 \leq R < 0 \end{cases}$$

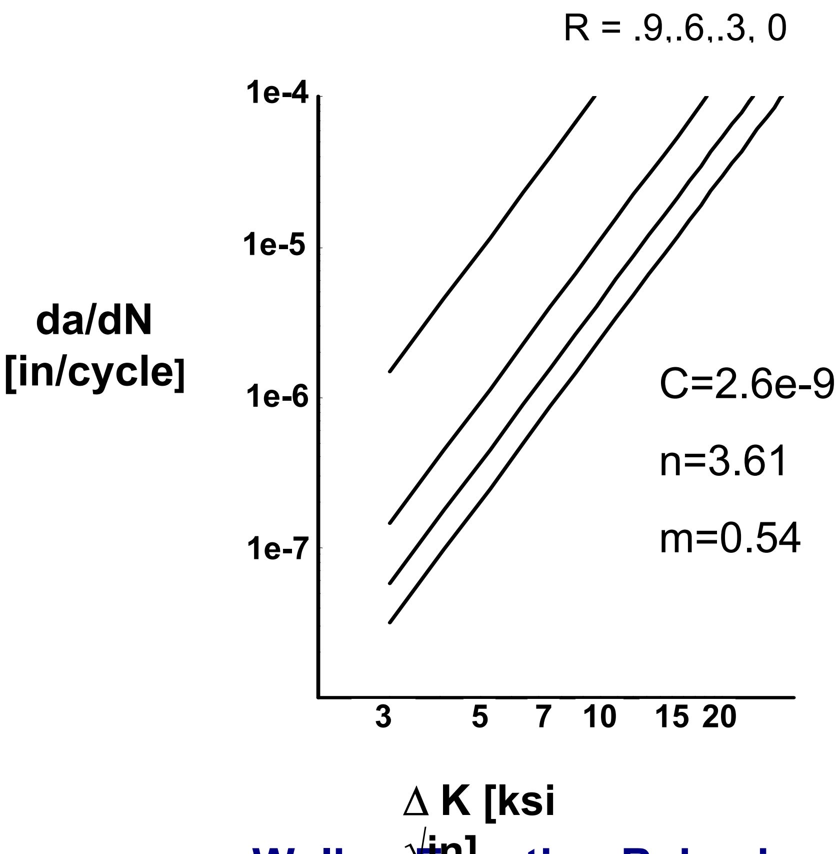
Walker Eqn:

$$\frac{da}{dN} = C\left[\frac{\Delta K}{(1-R)^{1-m}}\right]^{n}$$

Discrepancy between Walker & Closure Eqn's In Modeling R-Ratio Behavior

Example: Fits to NASMAT data (R = 0.1 to 0.7 data sets) for 7050-T7451 Al





Newman's Closure Equation Behavior

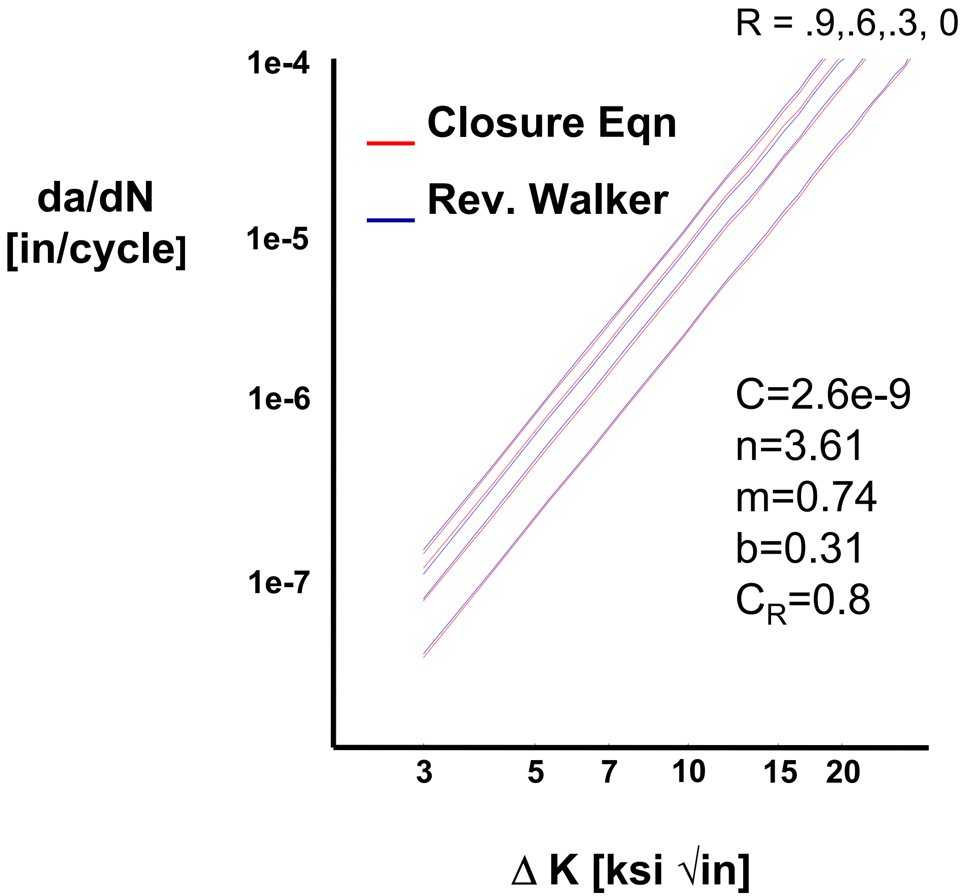
Curves converge with increasing R

Walker Equation Behavior

Curves diverge with increasing R

"Revised Walker Equation" & example fit to closure equation

Example Fit: NASMAT data for 7050-T7451 AL



$$\frac{da}{dN} = C\left\{\frac{\Delta K}{\left(1 - C_R\, R^{b}\right)^{1-m}}\right\}^{n}$$

Rev. Walker Equation

Summary

- **The recently received FAA funding is sufficient to complete all planned tasks on this project.**

- **This FAA project has continued to be very applicable and beneficial in improving crack growth analysis technology used in NASA space programs**

Fracture Mechanics R&D at JSC

Fracture Mechanics Development Teams:

- Experimental Projects Team

  Royce Forman (NASA)

  Scott Forth* (NASA)

- Analysis/Software Projects Team

  Joachim Beek *(NASA)

  NASGRO Contractor Support Team

  - V. Shivakumar, R. Christian, L Williams, F. Yeh, Y. Guo*

* New members

Planned Future Projects

Experimental and Computational Projects:

- Behavior of fatigue cracks growing from corrosion pits
- Effects of load interaction on fatigue crack growth
- Effects of environment and roughness on thresholds
- Development of da/dN data for numerous materials

- Improved multi-parameter crack instability model
- Fatigue crack growth through residual stress gradients
- Damage tolerance analysis of composite structures

- 3-D crack solutions for mechanical fittings, shafts, gears, etc.
- Hybrid 2-D BEM/FEM software module for layered joints